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Pointing Performance of the 8300 Series Datron Antennas

JAMES E. KENNEY AND ALAN P. SHARMAN

*Terrestrial Systems Branch
Space Systems Division*

August 16, 1982



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
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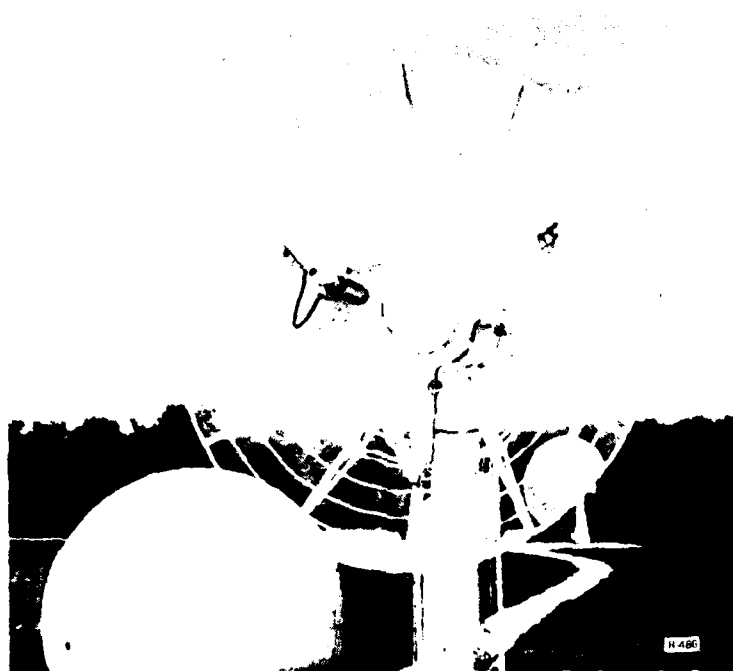


Fig. 1 — The Datron 6-m-diameter antennas

POINTING PERFORMANCE OF THE 8300 SERIES DATRON ANTENNAS

INTRODUCTION

The improvement plan for a Navy communication system requires the extending of the microwave-link capabilities to beyond 4 GHz. The existing antenna systems were tailored for L band, with antenna pointing characteristics specified to be commensurate with a nominal 2.5° antenna beamwidth. The antennas (Fig. 1) are 6-m-diameter parabolas manufactured by the Datron Corporation of Chatsworth, California.

The new link requirements call for a complete upgrading of the antenna reflecting surface which, when combined with the higher frequency, would produce a 3-dB beamwidth of approximately 0.75° . During the initial installation phase no comprehensive measurements were made to determine the pointing performance of the antennas over various portions of the hemisphere. No serious problems have been encountered during the system's operational phase at L band that can be attributed to antenna pointing. The rather large beamwidth, however, is very forgiving to minor errors in antenna-location and position-readout settings.

The lack of definitive pointing information and the antenna's inherent insensitivity to small errors might generate some risks when the antenna surfaces are upgraded and the beamwidth is decreased. Therefore a series of pointing measurements using the sun and the radio source Cassiopeia A were undertaken to determine the accuracy of the directional capabilities of the Datron antennas.

MEASUREMENT CONCEPT

The pointing accuracy was measured by using the continuum radiation properties of the sun and the radio source in Cassiopeia A as a far-field radio transmitter with accurately known positions as a function of time. The system's preamp and downconverter were followed by some suitable IF gain, detection, postdetection integration, and analog recording to form an uncalibrated total-power radiometer (Fig. 2).

Since only measurements of source position and not flux were the goal of the experiment, no attempt was made to provide a capability for calibrating the antenna temperature. A calibrated radiometer would have provided some additional information about the antenna collection system at L band, but since the radomes had already been proven deficient at 4 GHz [1] and need to be replaced or modified, the extra cost of a calibrated radiometer seemed unwarranted.

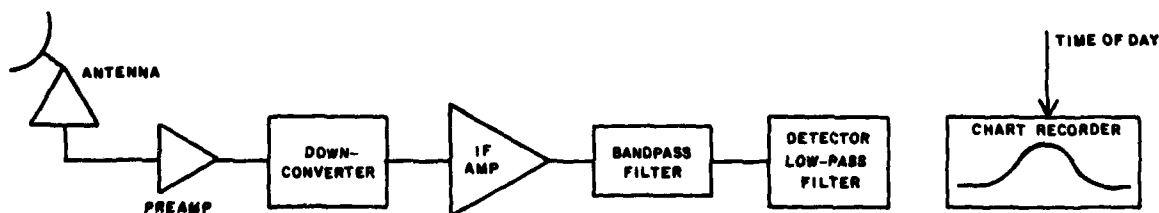


Fig. 2 - Radiometer

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The sun is an extremely strong radio emitter and provides a good means of measuring pointing accuracy for antennas with beamwidth of about 1° and larger. Cassiopeia A is the strongest radio star in the heavens, but since it is so distant, its expected antenna temperature is only approximately 11 K as compared to several thousand kelvins for the sun. Since its flux density is quite well established [2] and it is small in angular extent, Cassiopeia A can provide a good means for testing antenna efficiency and system performance.

Most of the pointing measurements were made using the sun, since it provided an almost infinite signal-to-noise ratio. The measurements using Cassiopeia A as a location source and the limitations of this source will be discussed later.

Celestial coordinates were converted to local azimuth and local elevation by programming a Hewlett-Packard 41C calculator to solve the necessary equations. The programmable calculator provided a convenient method for on-site real-time coordinate predictions. The program accepted the month, day of the month, antenna longitude, antenna latitude, source right ascension, source declination, and Greenwich mean time. It calculated local sidereal time, local elevation, local azimuth, and the angle with respect to the horizon that the source traversed the antenna beam. The local coordinates were given by

$$\arcsin El = \sin L \sin d + \cos L \cos d \cos LHA \quad (1)$$

and

$$\arccos Az = \frac{\sin d - \sin El \sin L}{\cos L \cos El} \quad (2)$$

where El is the elevation angle, L is the latitude, d is the declination, LHA is the local hour angle (local sidereal time minus right ascension), and Az is the azimuth angle. Appendix A provides the program listing and explanation.

MEASUREMENT PROCEDURES

For the measurements, the antenna was preset to a particular set of coordinates, and the radio source was allowed to drift through the antenna beam. A time history of the intensity pattern was recorded on an analog chart recorder. Figure 3 is an example of a drift-scan recording.

The small lobes on either side of the main pattern are the antenna's first sidelobes, which are down by 18.2 dB from the mainbeam pattern. The expected time of the antenna's peak response to the sun's energy is indicated. Each small division represents 12 s of time or 3 min of arc.

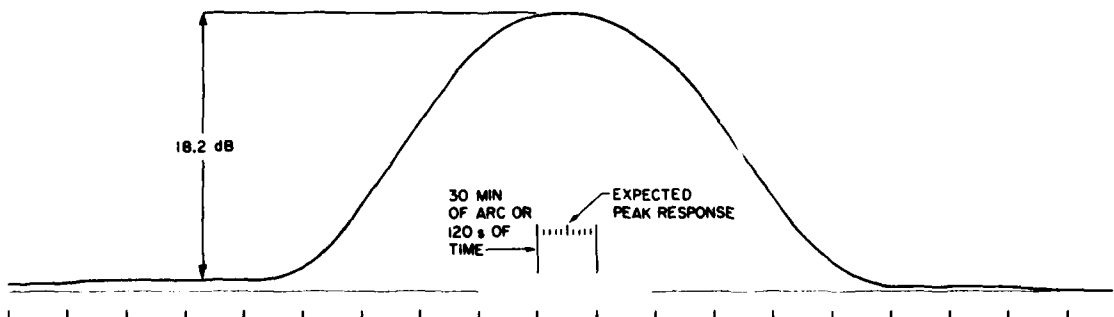


Fig. 3 — A drift scan pattern of the sun

Measurements were taken near the meridian with the antenna preset to the expected elevation and to the preset elevation $\pm 1^\circ$ to further verify elevation pointing. When the sun is near the meridian, its motion across the antenna beam is almost totally in azimuth. Measurements at the meridian were also taken with the antenna preset in azimuth to the expected azimuth angle plus 180° and in elevation to 180° minus the expected elevation angle (rotate and plunge) to gain some insight into the orthogonal accuracy of the two antenna axes.

EXPERIMENT RESULTS

To limit the cost of the measurements, only three stations were chosen for examination: Winter Harbor (in Maine), Guam, and Edzell (in Scotland). These sites were chosen because measurements by a System Test Evaluation and Calibration (STEAC) team had indicated a possible deviation in pointing from the original specifications. In all, seven of the nine antennas at these stations were measured. Only one antenna could be tested at Winter Harbor due to unrelated operational difficulties.

The antenna tested at Winter Harbor (antenna 2) exhibited results that were well within the $\pm 0.1^\circ$ pointing-accuracy specification. Figure 4 shows the deviation from no pointing error as a function of azimuth angle.

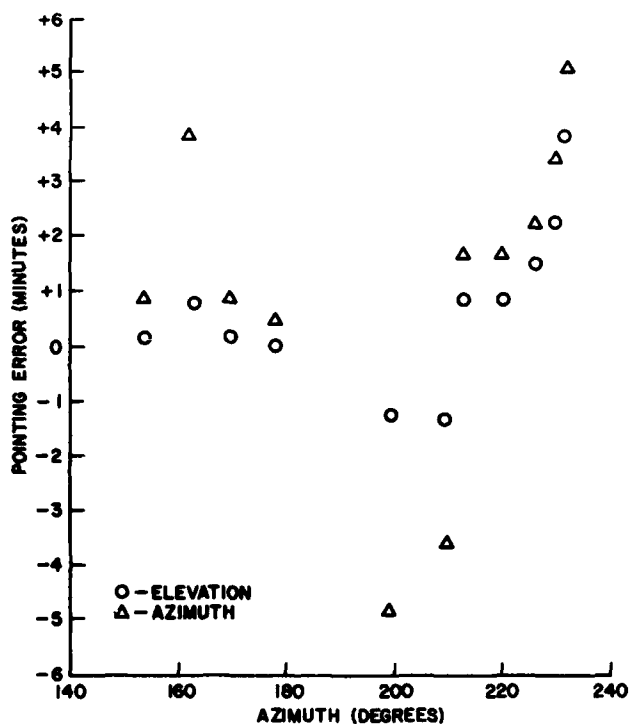


Fig. 4 — Pointing errors of a typical antenna
(Winter Harbor's antenna 2)

At the Guam site, antenna 2 displayed about the same pointing characteristics as the Winter Harbor antenna. Antennas 1 and 3 exhibited average pointing errors of about 13 and 25 min of arc respectively. The error appeared to be constant across the sky and was in azimuth only. The antenna's elevation-axis position readouts are set by leveling the antenna's backup structure and setting the readouts to 90° . The azimuth position readouts are set by pointing the Datron antenna being tested at the target antenna (a fixed testing antenna) and peaking the electrical response of the antenna being tested. The position readouts are then set to the azimuth position that is predetermined by a site survey. Table 1 compares the antennas' calculated azimuth vectors to the actual measured positions as obtained by the STEAC team's electrical boresight measurements. The calculated azimuths were arrived at by using the site-survey latitude and longitude coordinates of the Datron antennas and the target antenna.

The sun's position data were then corrected by the azimuth errors shown in Table 1. The scatter on the corrected pointing data falls within the $\pm 0.1^\circ$ specification and is disposed about the expected mean position. It remains, though, that the azimuth position readings of antennas 1 and 3 at the Guam site are in error by about 13 and 25 minutes of arc respectively. It can be determined from Fig. 3 that a Datron antenna's relative gain is flat within approximately 0.2 dB over the error interval; therefore the discrepancy would not be evident to the present system's operation. Such an error might prove disastrous to the improved system.

The antennas at Edzell were consistent with the general performance of the Winter Harbor and Guam units. The pointing errors are well within the $\pm 0.1^\circ$ specification levied on them.

Measurements of the sun's intensity made at Winter Harbor above and below the tree line showed that the trees around the antennas are introducing about 4.2 dB of loss into the microwave link. Figure 5 is a comparison of the sun's intensity patterns made at 7.5° elevation (above the trees) and 3° elevation (below the trees).

As was mentioned, a calibrated radiometer was not developed, since the measurement of flux densities was not a goal of this experiment. Some measurements were made using the radio star Cassiopeia A as a means of obtaining position measurements over a different part of the hemisphere. Cassiopeia A is at a high declination angle, and its motion draws a near circle in the northern sky. Its flux density is well known, and its expected antenna temperature can be easily calculated. The radio source flux density is related to antenna temperature by

$$S = \left(\frac{2kT_a}{KA} \right) \left(1 + \frac{D^2}{B^2} \right), \quad (3)$$

Table 1 — Azimuth Pointing Errors of the Datron Antennas on Guam as Determined by Comparison of the Boresight Positions and the Calculated Positions

Antenna	Antenna Readouts From the Electrical Boresite (deg)	Calculated Readouts From the Surveyed Coordinates (deg)	Readout Error (min)
1	100.71	100.283	+25.6
2	128.22	128.265	-2.7
3	159.58	159.356	+13.4

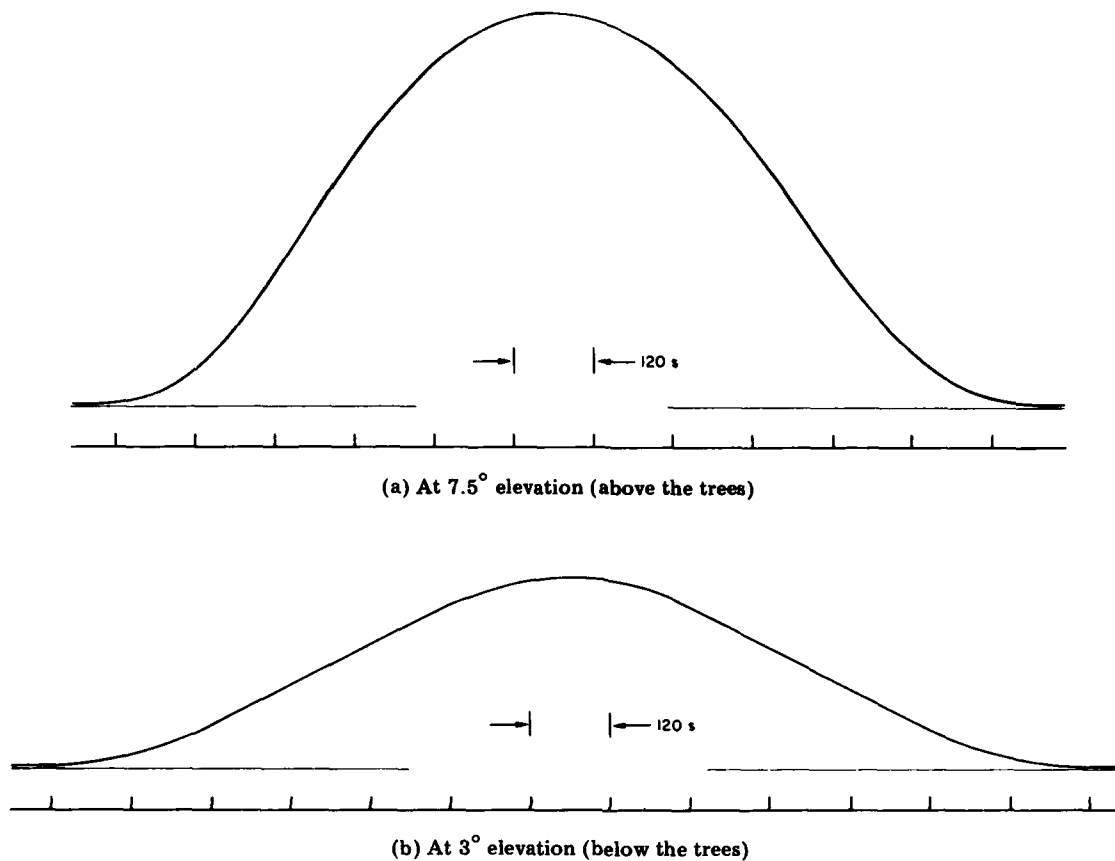


Fig. 5 — Effect of trees in reducing a sun intensity pattern at Winter Harbor

where k is Boltzmann's constant, T_0 is the antenna temperature, K is the antenna-aperture efficiency ($K = 0.55$), A is the area of the antenna aperture, D is the half-intensity width of the source brightness distribution, B is the antenna-beam half-width, and S is the flux in $(\text{W}/\text{m}^2)/\text{Hz}$.

The antenna temperature can be crudely estimated, in the absence of a calibration standard, by comparing the receiver fluctuations to the signal level introduced by the radio source. The system-noise fluctuations are expressed in terms of temperature in kelvins by

$$\Delta T_{rms} = \frac{(F - 1)T_0}{\sqrt{Bt}}, \quad (4)$$

where F is the system noise factor, T_0 is the sky temperature (in this case), B is the measurement bandwidth, and t is the postintegration time constant.

The expected antenna temperatures for Cassiopeia A as arrived at in this manner when compared with the measurements indicate unexplained losses in the system of about 1.5 dB. These are probably due to a combination of higher losses in the radome than were previously thought and an antenna-aperture efficiency of somewhat less than the presumed 55%. The information gained during this experiment cannot separate the sources of the loss.

CONCLUSIONS

The results of the measurements indicate that the present Datron antenna pedestals have suitable pointing integrity to support the system improvements. A couple of approaches to upgrading the surface tolerance of the antenna have been investigated by the antenna manufacturer [1].

Experience with the present method of antenna pointing by program tracking and its interaction with the antenna's servo system has shown that this tracking procedure produces unnecessary stresses on the antenna's driveline. Examination of the driveline failures that have occurred and the harsh treatment given to the drive gear train by some modes of program tracking strongly suggest that an autotrack pointing system be considered for the improved system. Program tracking could be retained as a backup tracking method. The Blossom Point, Maryland, facility uses autotrack.

Figure 6 is a demonstration of a sun-traced antenna pattern made with the radome-housed antenna at Blossom Point. As can be seen by comparison with Fig. 3, the Blossom Point antenna has considerably higher sidelobes than the other antennas. This is probably due to overillumination by the autotrack feed. Some investigation into improving these sidelobe characteristics should also be considered.

Extensive repair and maintenance procedures have been developed at NRL for the Datron antennas. Figure 7 shows the structure that was developed to replace the antenna's major drive gears. A tower is erected around an antenna pedestal inside a radome. The tower can lift the entire antenna superstructure off of the pedestal riser to allow gear changes. It was designed to be deployable and has been used at both Guam and Diego Garcia.

The improved system will require a fourth antenna at each site. Since the Datron antennas appear to be able to satisfy the pointing requirements that the improved system requires, and since the program has a large investment in logistic support and training for this antenna system, it would

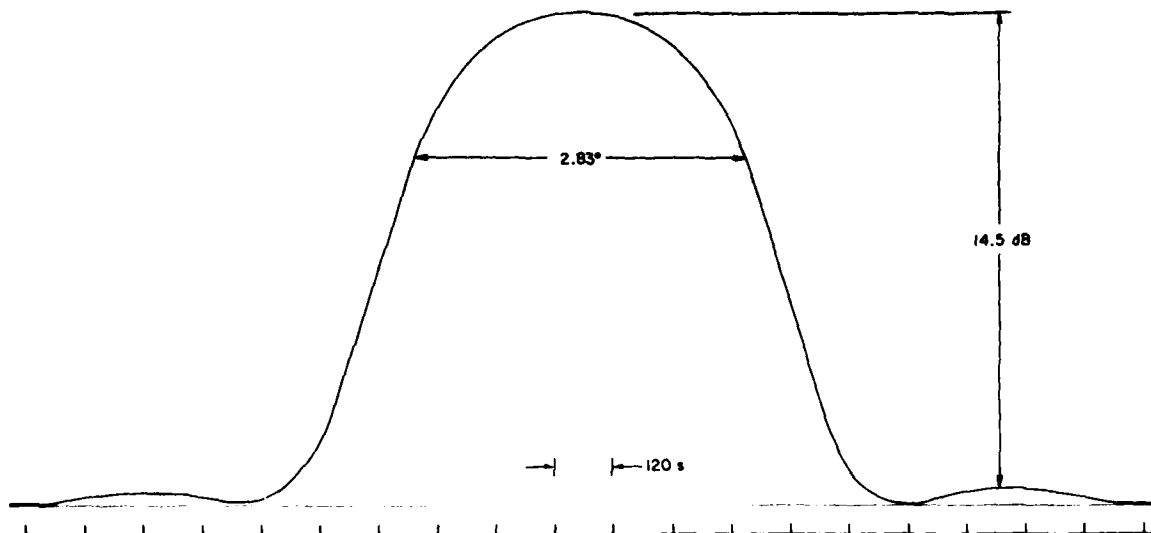


Fig. 6 — A drift scan of the sun by use of the radome-housed Blossom Point antenna

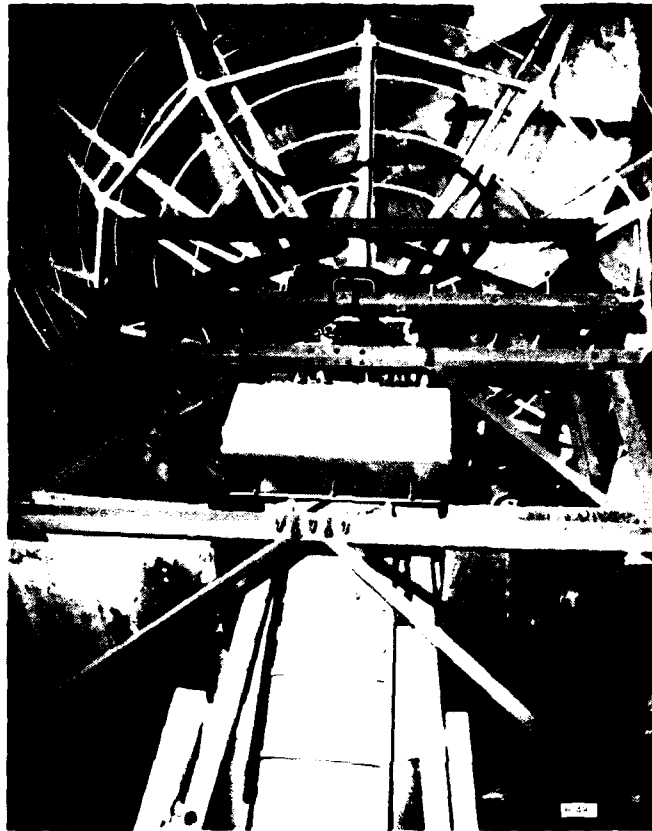


Fig. 7 — The antenna-disassembly structure, erected on Guam

appear prudent to install a fourth Datron antenna at each site. Since MILCON requires long lead times, some initiative should be taken soon to begin antenna procurement and site installations.

The problems presented by the high loss introduced into the microwave links by the present radomes at 4 GHz are being studied. The results will be reported when the study is complete.

ACKNOWLEDGMENTS

In general the authors thank everyone who contributed to resolving the small problems that arose during these tests. In particular the authors thank D. E. Watkeys for providing site survey data and helpful discussions, W. M. McDavit and the STEAC team for providing azimuth positioning information, E. F. Johnson for providing the graphics support, R. G. Bryant for getting the measurement equipment safely shipped to each site, and P. A. Townes for coping with many revisions while typing the manuscript.

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2. K. I. Kellerman, I. K. K. Pauliny-Toth, and T. P. J. S. Williams, "The Spectra of Radio Sources in the Revised 3C Catalogue," *Astrophys. J.* 157, 1-34 (July 1969).

Appendix A

PROGRAM TO CONVERT CELESTIAL COORDINATES TO LOCAL COORDINATES

This appendix contains instructions for and a listing of the coordinate-conversion program used in the measurements. The program is written for the Hewlett-Packard 41C programmable calculator. The program calculates local sidereal time and then by use of Eqs. (1) and (2) given in the main text converts celestial coordinates to local azimuth and elevation.

A constant must be inserted into the local-sidereal-time calculation that is consistent with the year located in location 8 in the program memory. The constant is in location 66. The constant is derived by dividing by 24 the sidereal time (in decimal hours) for 0 hours on January 0 of the appropriate year. This time is available in the American Ephemeris and Nautical Almanac for the proper year.

Southern latitudes and east longitudes are entered as negative numbers. The subroutine DEL calculates the angle with respect to the horizon that the source travels through the antenna beam. The constant in location 165 is the approximate number of minutes required for the source to traverse the antenna beam and should be entered as appropriate. The program will operate with or without a printer. If a printer is not available, the solutions can be obtained by recalling the desired locations in the data memory as noted in the operating instructions.

The program is run as follows:

Enter	Press	Display
Month (1 through 12)	Enter	Month
Day of month (1 through 31)	XEQ "B"	Day of year
Latitude (dd.mmss)	Enter	Latitude
Longitude (dd.mmss)	XEQ "D"	current year
Declination	Enter	Declination
Right ascension	XEQ RA,	Right ascension in degrees
Greenwich mean time	XEQ LST	Azimuth

Data-Memory Location	Output
00	Local sidereal time
01	Latitude
02	Longitude
03	Day of year
04	Month
05	Declination
06	Right ascension
07	360
08	LHA
09	Sin <i>E</i>
10	<i>E</i>
11	Azimuth
12	GMT

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The listing is as follows:

01<>LBL D	50 15	99 RCL 08	148 RTN
02 FIX 5	51 *	100 COS	149 XEQ"DEL"
03 HR	52 STO 06	101 *	150 ADV
04 STO 02	53 X<>Y	102 +	151 ADV
05 X<>Y	54 HR	103 STO 09	152 RTN
06 HR	55 STO 05	104 ASIN	153<>LBL C
07 STO 01	56 RTN	105 STO 10	154 RDN
08 1982	57<>LBL "LST"	106 RCL 05	155 STO 11
09 RTN	58 STO 12	107 SIN	156 GTO "PR"
10<>LBL B	59 RCL 02	108 RCL 09	157 RTN
11 X<>Y	60 360	109 RCL 01	158 <>LBL "DEL"
12 STO 04	61 STO 07	110 SIN	159 SF 01
13 3	62 /	111 *	160 RCL 11
14 X>Y?	63 1	112 -	161 STO 17
15 GTO A	64 X<>Y	113 RCL 01	162 RCL 10
16 RDN	65 -	114 COS	163 STO 18
17 1	66.275923	115 /	164 RCL 12
18 -	67 +	116 RCL 10	165.12
19 31	68 X<>Y	117 COS	166 HMS+
20 *	69 HR	118 /	167 XEQ "LST"
21 +	70 24	119 ACOS	168 CF 01
22 STO 03	71 /	120 RCL 08	169 RCL 11
23 ENTER@	72 RCL 03	121 SIN	170 RCL 17
24 4	73 +	122 X<O?	171 -
25 /	74 1.0027379	123 GTO C	172 RCL 10
26 FRC	75 *	124 RDN	173 RCL 18
27 RCL 03	76 +	125 RCL 07	174 -
28 +	77 FRC	126 X<>Y	175 X<>Y
29 INT	78 24	127 -	176 R-P
30 RCL 04	79 *	128 STO 11	177 "DPOS="
31 .4	80 HMS	129 GTO "PR"	178 ARCL X
32 *	81 STO 00	130 RTN	179 AVIEW
33 2.3	82 RCL 00	131<>LBL "PR"	180 X<>Y
34 +	83 HR	132<>"GMT="	181 "THETA="
35 INT	84 15	133 ARCL 12	182 ARCL X
36 -	85 *	134 AVIEW	183 AVIEW
37 STO 03	86 RCL 06	135 "LST="	184 RTN
38 RTN	87 -	136 ARCL 00	185 END
39<>LBL A	88 STO 08	137 AVIEW	
40 RDN	89 RCL 01	138 "LHA="	
41 1	90 SIN	139 ARCL 08	
42 -	91 RCL 05	140 AVIEW	
43 31	92 SIN	141 "AZ="	
44 *	93 *	142 ARCL 11	
45 +	94 RCL 01	143 AVIEW	
46 STO 03	95 COS	144 "EL="	
47 RTN	96 RCL 05	145 ARCL 10	
48<>LBL "RA"	97 COS	146 AVIEW	
49 HR	98 *	147 FS? 01	

